من ذكريات العمل (31)

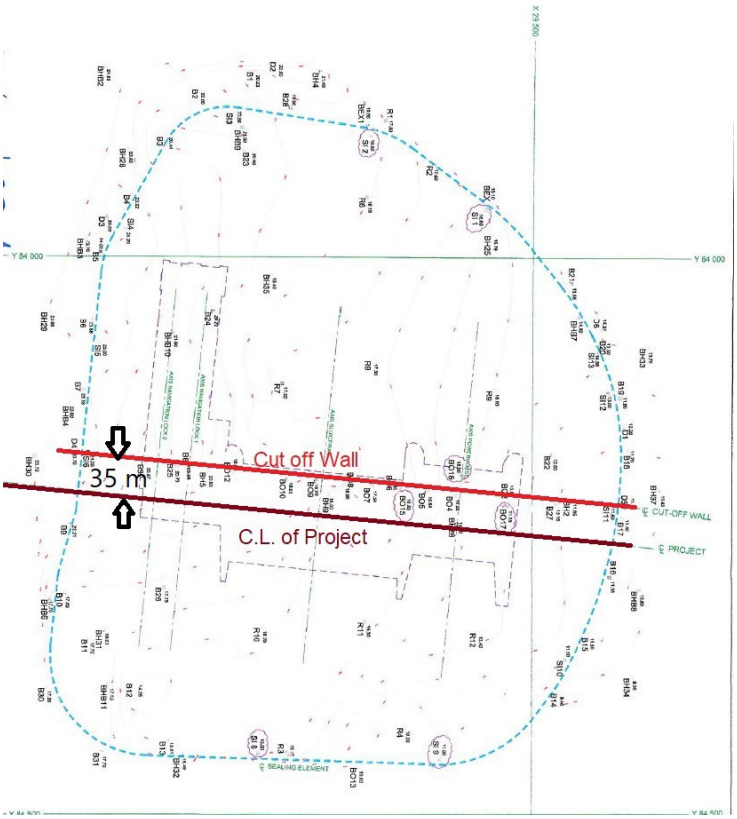
مشروع قناطرنجع حمادى الجديده

الستارة الدائمة (Permeant Cut off Wall)

مقدمة

تُعد الستارة الدائمة (Permanent Cut-off Wall) عنصرًا أساسيًا في المشروعات المائية مثل السدود والقناطر، حيث تُشكل خط الدفاع الرئيسي ضد تسرب المياه من أسفل المنشأ أو حوله. وهي عبارة عن حائط أو حاجز خرساني غير منفذ أو شبه منفذ يمتد إلى أعماق محددة في التربة أسفل الأساسات.

تُصمم الستارة للحفاظ على فرق التوازن الهيدروليكي المطلوب بين الجانب الأمامي (Upstream) والخلفي (Downstream) للمنشأ، حيث يتراوح هذا الفرق فى مشروع نجع حمادى من 3.5 إلى 8 أمتار (من منسوب 65.90 إلى 58.00 في فترة الحد الأدنى للاحتياجات، ومن 65.90 إلى 62.50 في فترة الحد الأقصى للاحتياجات). هذا التصميم يضمن التحكم في الضغوط المائية الجوفية، ويمنع ظواهر خطيرة مثل الرفع الهيدروليكي (Uplift) والانجراف الداخلي للتربة(Piping) ، مما يعزز استقرار المنشأ المائي على المدى الطويل.



وصف الاعمال

تمتد الستارة الدائمة من قناة التحويل من الناحية الغربية بعد ردمها الى تحت أساسات محطة الكهرباء والمفيض والأهوسة الملاحية قاطعة الستارة المؤقته وتمتد ايضا لتصل الى الستارة المؤقتة فى الناحية الشرقية لتتقاطع معها بجوار الهوسة الملاحية .

يبلغ طول الستارة حوالى 725 متر وتقع على مسافة 35 مترا من محور المشروع من جهة الامام وتتكون من الخرسانة البلاستيكية (Plastic Concrete) وتصل الى اعماق من 35 الى 50 مترا وبسمك 80 سنتيمتر وتمتد الى الطبقة الصماء من الطين (Hard Clay Layer) وتخترقها بعمق لا يقل عن 1.50 مترا .

تم تنفيذ الاعمال على مرحلتين

(المرحلة الأولى) اسفل المنشات الرئيسية محطة الكهرباء والمفيض والاهوسة الملاحية من منسوب منصة عمل 48.8 م فوق سطح البحر

كان المقاول قد طلب الموافقة باعتبار منصة التشغيل للمرحلة الاولى على منسوب واحد ثابت وهو 48.8 بدلا من المناسيب التصميمية المختلفة للمنشات الثلاثة لسهولة التنفيذ ووافق عليهاالاستشارى والمالك وهى كالاتى :

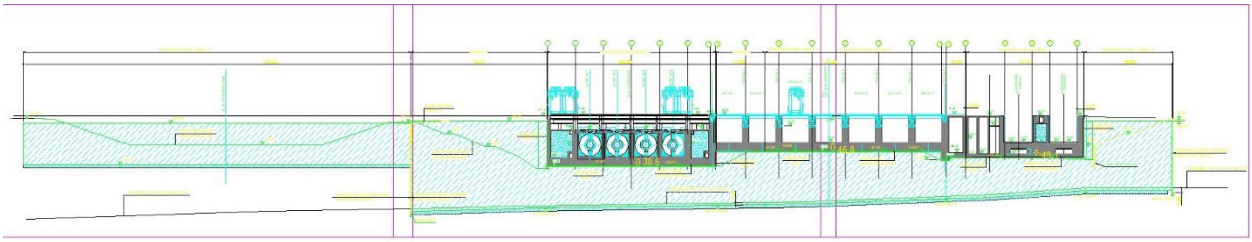
محطة الكهرباء 37.60

المفيض 46.8

الاهوسة الملاحية 43.1

أما(المرحلة الثانية)، فتم تنفيذها من منصتين على مناسيب 67.1 من الناحية الشرقية بطول 55.5 مترا.

ومن الناحية الغربية على منسوب 67.5 م بطول 331 مترا اسفل قناة التحويل.



المواد المستخدمه ومكونات الخلطة

مكونات الستارة الدائمة هى نفسها مكونات الستارة المؤقتة من حيث المواد والنسب لكل متر مكعب وهى كالاتى :

136 كيلوجرامًا من الأسمنت(Cement)

821 كيلوجرامًا من الرمل(Sand)

671 كيلوجرامًا من الزلط (Gravel)

35 كيلوجرامًا من البنتونايت (Bentonite)

380 كيلوجرامًا من الماء(Mixing Water)

تتكون الستارة من وحدات (Pannels) ابتدائية وثانوية

مواصفات هذه الخرسانة:

Compressive Strength ≥0.35 mpa

Elastic Modulus ≥1000mpa

Modulus of Elasticity = 350-1000mpa

Slump for fresh concrete= 20-25 cm

Permeability $\geq 1*10^{-8}$ m/sec

Strain at Failure ≥0.6

خطوات التنفيذ

أ- منسوب التشغيل

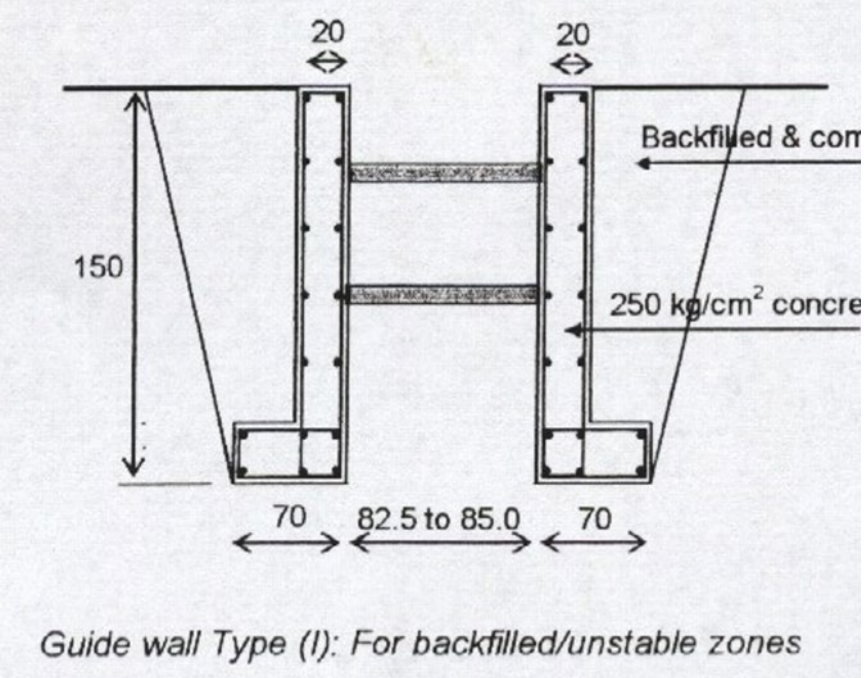
تم اختيار منسوب (48.80)ليكون هو المنسوب الذى سيتم منة عمليات الحفر وصب الخرسانة البلاستيكية لمكونات المشروع الثلاث(محطة الكهرباءوالمفيض والاهوسة الملاحية)

ب- الحوائط الموجهة (Guide Walls)

تم اختيار قطاع .L SEC سابق الصب بابعاد 25*150 سم وابعاد للحائطوابعاد 70*25 سم للقاعدة وبطول 6 متر كما موضح بالرسم المرفق من الخرسانة المسلحة و تم تثبيتها وضبط محاورها واجنابها فى الموقع وذلك من منسوب واحد هو (48.80) كما سبق ذكرة.وترجع فائدة الحوائط الموجهة الى الاتى:

- كدليل للتأكد من المحور الصحيح للحائط

- حماية الجزء العلوى من التربة من الانهيار.
- تدعيم وتثبيت اتزان المنطقة العلوية من الستارة والتى تتاثر بحركة المعدات الثقيلةالمجاورة



Guide wall Type (I): For backfilled/unstable zones

حفر الحوائط وابعادها

قبل البدء فى العمل تم الحفر التجريبى لعمق 3.00 متر بواسطة الحفارات العادية وذلك لتوفير العمق اللازم لماكينة الحفر Trench Cutter لبدء عملية والحفر.

حفر الحوائط الابتدائية

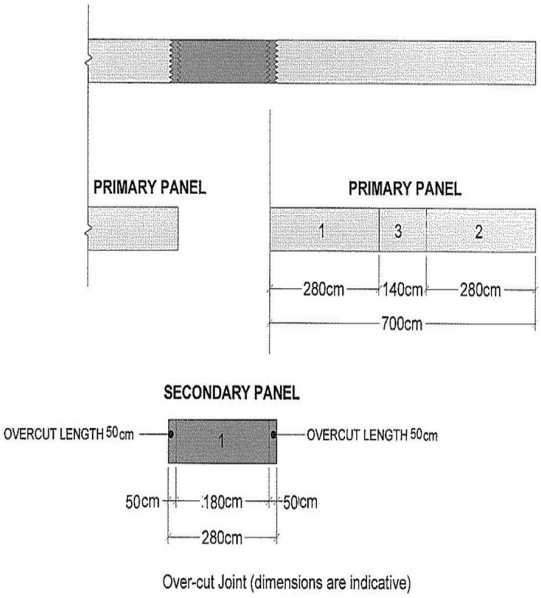
يتم حفر الحائط الابتدائى ذو العرض 7.00 متر على ثلاث مراحل عرض كل من المرحلة الاولى والثانية 2.8 متر وعرض المرحلة الثالثة 1.4 متر ووهى فى المنتصف كما سبق ذكرة فى الستارة المؤقتة.

حفر الحوائط الثانوية وعمل الوصلات

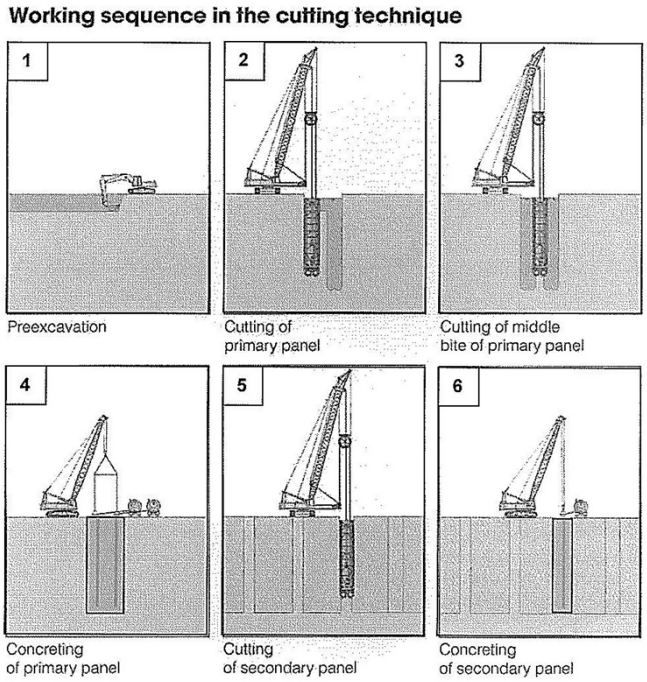
بعد حفر وصب الحوائط الابتدائية فانه يتم حفر الحوائط الثانوية حيث تترك مسافة بين الحائطين الابتدائيين قدرها 1.8 متر وذلك ليتم حفر وصب الحوائط منها ومن المعلوم ان طول الهيكل الخاص بماكينة الحفر هو 2.80 متر فانة يكون مسافة القطع فى الحائط الابتدائى المجاور هى 50 سم من كلا الناحيتين وينتج من ذلك القطع سطح متعرج فى كل من الناحيتين .

وبمجرد صب الحوائط الثانوية فان التعرجات الموجودة فى الحوائط الابتدائية سوف تجعل هناك اتصال جيد بين الحوائط الابتدائية وبين الخرسانة البلاستيكية حديثة الصب للحوائط الثانوية .

مدة المعالجة المطلوبة تتراوح من 7-14 يوما وذلك حتى يتم صب الحوائط الثانويةالمجاورة بين الحوائط الابتدائية .

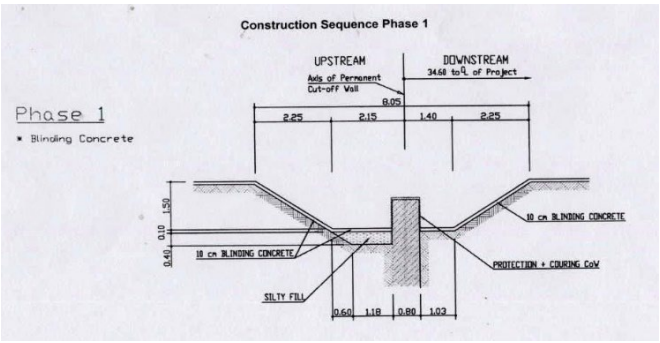


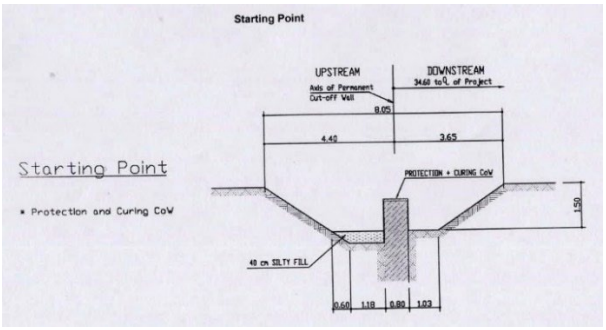
Over-cut Joint (dimensions are indicative)

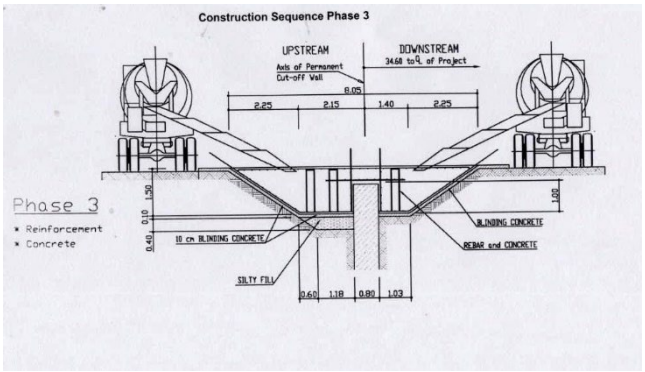


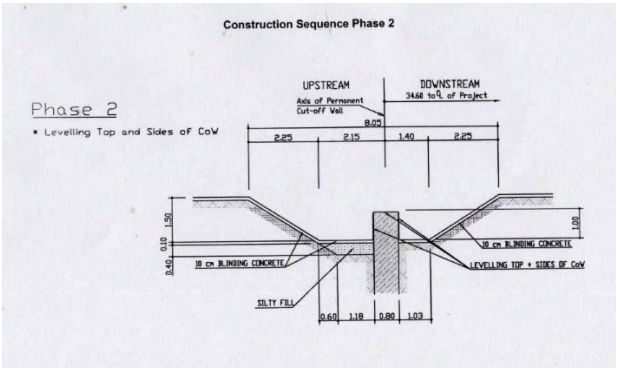
رسومات تفصيلية للتقاطعات

<u>ربط الستارة مع اسفل المنشآت الرئيسه</u>



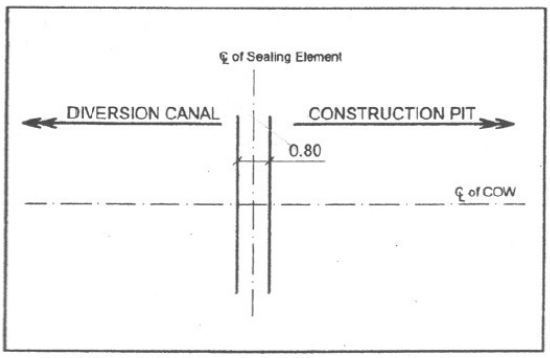




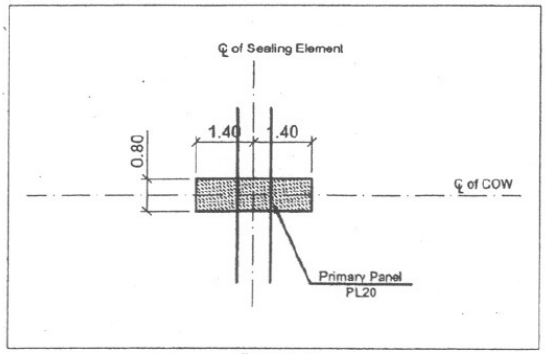


ثانيا الربط مع الستارة المؤقته من الناحية الشرقية والغربيه

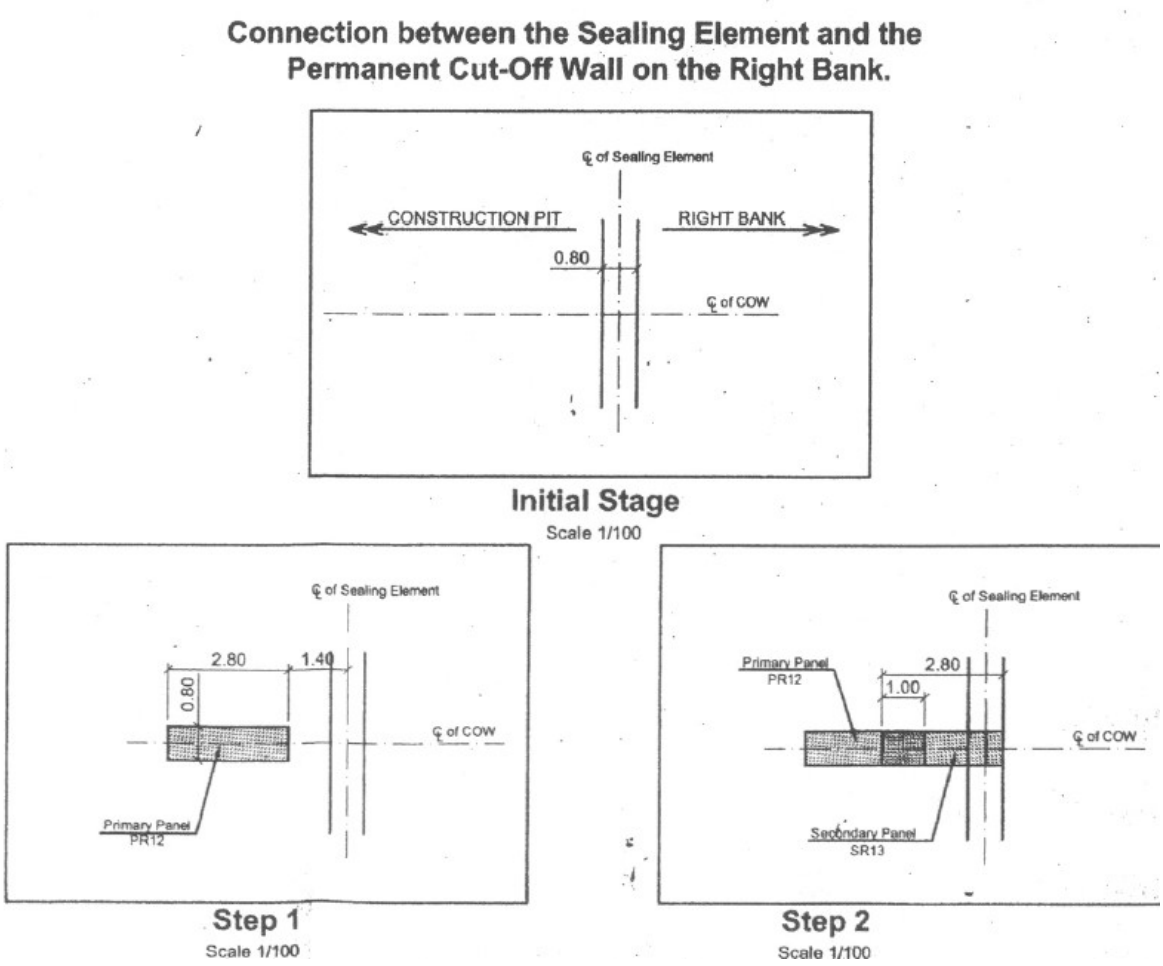
Connection between the Sealing Element and the Permanent Cut-Off Wall on the Left Bank.



Initial Stage
Scale 1/100



Step 1
Scale 1/100



صب ونقل الخرسانة البلاستيكية

تم نقل الخرسانة البلاستيكية من محطة الخلط الى موقع الحوائط بواسطة السيارات بمعدل صب حوالى 35 م3/ساعة للحوائط الابتدائية ذات عرض 7.00 متر وذلك لتحقيق معدل رفع للخرسانة داخل الحفريتراوح من 20-50 سم لكل دقيقة كما هو موضح فى المواصفات الفنية للمشروع.

كذلك فان عدد مواسير الصب سوف يتم تحديدة بناءا على طول الحائط ففى الحوائط الابتدائية تم استخدام خطين للصب وفى الحوائك الثانوية تم استخدام خط واحد فقط .

كما انة يجب ملاحظة انه وقبل بدء الصب يتم انزال خط الصب بحبث يلامس قاع الحفرة ويتم رفعة بعد ذلك بمقدار 50 سم

طريفة صب الخرسانة البلاستيكية

كما يجب خلال جميع مراحل الصب يجب ان يكون خط الصب مغمورا فى الخرسانة بمقدار 3.00 متر.

وفى حالة استخدام 2 خط صب فى حائط ابتدائى واحد فان كل خط يتم الصب فيه من خلال سيارة صب ويتم رصد منسوب الخرسانة بجوار كل خط على حدة حتى لا يرتفع منسوب الخرسانة فى خط عن الاخر.

وخلال عملية الصب فانة يتم ازاحة البنتونايت الى اعلى والذى يتم سحبة بواسطة طلمبة بجوار الحفر وضخة الى احواض او صوامع البنتونايت

ويستمر الصب حتى يصل الى منسوب 1.5 متر اسفل منسوب جسر التشغيل او اسفل قاع الحوائط الموجهة .

اعتبارات هامة

بعد دراسة طبقات التربة المختلفة تحت مكونات القناطرالثلاث (محط الكهرباء-المفيض-الاهوسة الملاحية) ومن واقع ابحاث التربة فانة تم تحديد مقدار اختراق الحائط القاطع (الستارة الدائمة) تحت المنشا فى طبقة الطين الصلب (clay layer) بمقدار 1.5 متر وهى مسافة اقل من مثيلتها فى الستارة المؤقتة حيث كانت ثلاثة امتار وقد كانت هذة نقطة خلاف بين الشركة المنفذة والاستشارى وقد اوضح الاستشارى مبرراته الفنية حيث ان هناك اختلافات بين حيث نوعية الضغوط التى تتعرض لها الستارة الدائمة والستارة المؤقته كما أظهرت الاختبارات المعملية المكثفة أن خواص طبقة الطمي/الطين تسمح بتقليل عمق تأسيس الستارة القاطعة (Cut-Off Wall) داخل هذه الطبقة من 3.0 م إلى 1.5 م فقط .وقد استند هذا القرار إلى نتائج التنفيذ الفعلي للستارة القاطعة المؤقتة(Sealing Element Cut-Off Wall) ، والتي أثبتت دقة تحديد عمق الاختراق المطلوب وقد قبل كلا من المالك والمقاول هذه النتائج.

كما قام كلا من الاستشارى والمالك برفض طلب المقاول بتقليل مسافة القطع لتكون 26 سم بدلا من 50 سم فى الحوائط الثانوية ولم يقدم مبررات فنية او تعاقدية لمخالفة المواصفات الفنية فى العقد وواضح ان طلب المقاول كان لتقليل التكلفة.

وتجدر الاشارة هنا ان الطريقة العملية لمعرفة الوصول الى منسوب طبقة الطين اثناء الحفر هى ملاحظة ومراقبة ال Desander (وحدة استعادة البنتونيت وفصله عن الرمل) حيث انه عند ظهور هذة الطبقة تظهر كرات صغيرة من الطين فى منتصف ال Desander يمكن ملاحظتها بوضوح تام وعند ذلك يتم تحديد المنسوب العلوى لطبقة الطين .

كما يمكن تحديد هذة الطبقة ايضا من خلال ملاحظة الشاشة الخاصة بماكينة الحفر حيث يلاحظ اختلاف الضغط الواقع على التروس القاطعة ويزداد فجاة وحينئذ يتم تحديد المنسوب العلوى لهذة الطبقة .

المعدات والأدوات الرئيسية(Key Equipment)

- **Trench Cutter BC30مثبتة على رافعةLiebherr 883 ، مزودة بتروس دوارة عكسية، طلمبة 400 م³/ساعة، و Inclinometerللرأسية.**

تشكّل ماكينة الحفر (Trench Cutter) قلب عملية الحفر العميق، مدعومًا برافعة جنزيرية ذات سعة رفع كبيرة تسمح بالمناورة الدقيقة فوق الحوائط الدليلية.

واثبتت هذه الماكينة انها افضل من الطريقة التقليدية لحفر الحوائط باستخدام ال (Grap) خيث تعطى جودة عالية نسبيا وسماحية صغيرة جدا واعماق حفر كبيرة تتطلب معدات وآلات حفر ذات دقة عالية اعلى بكثير من طريقة الحفر التقليدية باستخدام ال(Grap)

وحدة استعادة البنتونيت Desander BE500

- فصل الرمال من البنتونيت.

تولّت وحدة فصل الرمال والطين (Desander) استعادة البنتونايت وإعادة ضبط خصائصه، فيما قامت وحدة الخلط المركزية (Mixing Unit) بإنتاج الخرسانة البلاستيكية بمعيارية ثابتة وإرسالها بسيارات الخلط إلى موقع العمل

- **خلاط** :**BM1000** مع صوامع تخزين 20 م^3 ومهدئات.
- **طلمبات ومعدات مساعدة**Haberman KPKT

وحدة فصل مكونات ناتج الحفر (Desander)

الفوائد الرئيسية لاستخدام هذا النوع من الماكينات

1- القدرة العالية على حفر اعماق اكبر للحوائط اللوحية او الستائر (Cut-off wall)وذلك بانزال اداة الحفر مرة واحدة حتى يتم الحفر الى العمق المطلوب

2- تعطى مستوى عالى الدقة وسهولة مراقبة كل عمليات الحفر والتحكم فيها

3- تعطى وصلات متينة بين الحوائط وذلك باعادة القطع فى اطراف الحوائط المجاورة والتى سبق صبها

4- عدم وجود ضجيج او اهتزازات للتربة اثناء الحفر وبذلك تقلل كثيرا من التلوث الضوضائى وتعطى درجة امان كبيرة للمنشآت المجاورة

مراقبة راسية الحفر

اثناء الحفر يجب التاكد من راسية هذة الحوائط وكذلك تفادى حدوث اى انحراف كبير فى اى اتجاة سواء كانت فى اتجاة الستائر المؤقتة او عمودى علية ويوجد جهاز خاص فى ماكينة الحفر (Trench Cutter)يقوم برصد هذا الانحراف ويسمى Inclinometer ويتم الرصد اولا باول كما اتها مزودة بجهاز مراقبة وتحكم بة وحدة كمبيوتر تقوم بتسجيل والتحكم فى الراسية فى اتجاهين متعامدين مع تقدم سير الحفر ويقوم هذا الجهاز بتصحيح الراسية اولا باول لتكون فى الحدود المسموح بها طبقا للمواصفات .

هذا وقد كان الانحراف المسموح بة :

الانحراف فى اتجاة x او y= 0.5%

ولتقريب المفهوم فانة اذا كان عمق الحفر 60 متر فان الانحراف المسموح بةهو 30سم فى نهاية العمق .

وتجدر الاشارة هنا انة تم تنفيذ الستارة بدقة راسية عالية لم يتعدى الانحراف فى الاتجاهين مقدار 5سم فقط.

خاتمة

اردت التذكير بها العمل وشكر كل من شارك فيه ومتعه الله بالصحة والعافية والترحم على من انتقل الى جوار ربه رحمهم الله رحمة واسعة.

PART 2 – CONSTRUCTION REPORTS

ANNEX 4

CUT-OFF WALL

CONSTRUCTION REPORT

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1 INTRODUCTION

A new barrage with integrated hydropower plant is under construction to replace the old barrage in Naga Hammadi. This is located about 360 km downstream of the Aswan High Dam on the Nile River in Upper Egypt. The new barrage under construction is 3.5 km downstream of the old barrage structure. The decreasing width of the riverbed and the existing geological conditions with a bottom Silt/Clay layer allow at the chosen location the excavation of an up to 29.1 m deep almost circular construction pit in the old riverbed and neighboring river banks with 25 m depth below the river water level. Below the permanent concrete structures, 35 m upstream of the center line of the project, a Cut-Off Wall was constructed in "Phase 1" which is keying into the natural bottom sealing by 1.5 m for erosion control.

This section of the Cut-Off Wall intersects at both ends with the temporary sealing element.

Phase 2 of the Cut-Off Wall comprises the continuation of the Phase 1 wall at both ends in to the east and west river embankments. These 2 sections could only be constructed in the late phase of the project after backfilling both abutments and after closure of the river diversion.

These sections of the Cut-Off Wall intersect with the temporary sealing element left in place at both abutments.

The length of the Phase 2 Cut-Off Wall is:

- 55.5 m on the right side (eastern) embankment
- 331 m on the left side (western) embankment

2 SCOPE OF WORK AND GEOMETRY

The Cut-Off Wall under permanent structures, "Phase 1" is executed as a Two Phase Plastic Concrete Slurry Cut-Off Wall which is tied 1.5 m into the below described "impermeable" and solid to hard Silt/Clay layer.

By request of the Contractor, the works were carried out from one working platform at level 48.8 m asl, whereas the designed heads of the wall are different as follows:

- Powerhouse: COW head at 37.60 m asl
- Sluiceway: COW head at 46.80 m asl
- Sluiceway Abutment Pier: COW head at 46.80 – 41.50 m asl
- Navigation Locks: COW head at 43.10 m asl

The overall executed wall area is rounded 8998 m^2 (from Measurement for Payment):

The design of the Cut-Off Wall (COW) as a 2-Phase Slurry Cut-Off Wall was prepared by NHBDC. The design of the plastic concrete for the temporary Sealing Element Cut-Off Wall around the Construction Pit, Mixture M1 was suitable and chosen by NHBDC based on structural and deformation calculations.

The Cut-Off Wall of Phase 2 is executed like the COW of Phase 1 as a Two Phase Plastic Concrete Slurry Cut-Off Wall; the sections adjacent to the structures are tied 1.5 m into the below described "impermeable" and solid to hard Silt/Clay layer, the section across the former Diversion Canal reaches to level 39.00 m asl (see **Attachment 6**).

The works were carried out from working platform levels 67.50 m asl in the Diversion Canal area and on the right embankment and 68.1 m asl in the area of the Gantry Crane rails where backfill had already been completed. The COW head level including over-pouring is 66.30 m asl for Phase 2 COW.

The overall executed wall area of Phase 2 is 13,674 m^2.

3 SUBSOIL CONDITIONS

3.1 General Geology

The project area is entirely located within geologically young alluvial Nile deposits consisting of alternating layers of poorly graded, partly silty, fine to medium/coarse grained sand and gravel. The youngest and uppermost layer is the holocene partly clayey, sandy silt with some 4 to 13 m thickness ("Nile Silt"). Below follows pleistocene sand, gravel, and partly cobbles and boulders were encountered, with a thickness ranging between 35 m and more than 60 m. The pleistocene silt/clay layer consists of silty clay/clayey silt with portions of fine sand with a varying thickness between approximately 3 m and 12 m. The top of the bottom Silt/Clay layer was found according to the geotechnical investigations at levels between 13.7 m at the Powerhouse western edge and at the 19.9 m at the Navigation Locks eastern edge.

3.2 Pre-Construction Investigations

Between the years 1993 and 2000 geotechnical investigations were carried out in five stages; 16 boreholes were drilled onshore and 6 boreholes offshore at the new Barrage location. In addition, 23 exploratory boreholes have been drilled in April/May 2000 at the construction pit location. The purpose of the investigations was to condense the grid of boundary information about the Pleistocene Silt/Clay layer at depth.

At depth, a Silt/Clay layer was found in 21 out of 23 boreholes of the drilling campaign in April/May 2000. The top of the layer was located between 24.8 m asl and 10.0 m asl. In these 21 boreholes, the bottom elevation of the layer was found between 17.4 m asl and 3.1 m asl with a thickness of the layer ranging from 5.3 m to 12.2 m. In two boreholes, B1 and B5 near the south- eastern area of the Construction Pit at the upstream end of the navigation lock, no Silt/Clay layer could be identified in the respective depth. The following investigations were performed by the Contractor near to the alignment of the permanent Cut-Off Wall before the start of the COW construction works.

3.3 Investigations after Commencement of the Works

Along the COW alignment, the following boreholes were carried out for the investigation of the top level of the Silt/Clay layer and its soil mechanical properties to a minimum depth of 4.5 into it (from west to east):

BOREHOLE NO.	TOP OF SILT/CLAY (M ASL)
B02	13.68
B04	14.22
B05	15.94
B06	17.85
B07	17.58

BOREHOLE NO.	TOP OF SILT/CLAY (M ASL)
B08	18.90
B09	18.79
B010	19.55
B012	19.87

The layout of the Construction Pit with the location of the investigation boreholes including the figures of the top level of the Silt/Clay layer is attached as **Attachment 1.**

4 BASIC DESIGN DETAILS

4.1 Design Criteria

As per Tender Design, the Cut-Off Wall was defined as a 0.80 cm thick two-Phase Slurry Cut-Off Wall, keying 3 m to the "impermeable" bottom Silt/Clay layer in 45 to 55 m depth below the natural bank levels.

After the determination of the 'Exploratory Investigation' during construction, NHBDC changed the design by keying into the Silt/Clay layer by only 1.5 m. The following target values for the plastic concrete were defined in detail based on the Exploratory Investigation and Numerical Model Calculations:

- Permeability $k \leq 1 \times 10\text{-}8$ m/s (28 days) (PTS)
- Modulus of Elasticity $Es \leq 350$ MPa for average of samples, max. 25 % of samples > 350 MPa (28 days after sampling) (NHBDC)
- Uniaxial Compressive Strength (UCS) $qu \geq 1.00$ MPa (28 days) (NHBDC)
  (max. 25 % of samples > 0.8 MPa < 1.0 MPa)
- Workability of fresh concrete (slump) 220 to 250 mm (Method Statement)

The uniaxial minimum value was chosen due to erosion stability and structural strength.

4.2 Plastic Concrete Trial Mixes

For the Sealing Element Cut-Off Wall, the Contractor tested Trial Mixes of plastic concrete which are documented here as well, because the results were later used also for the permanent Cut-Off Wall. The following concrete constituents and the maximum temperature were chosen for the Trial Mixes:

- Type of Ordinary Portland Cement (OPC)
- Maximum size of coarse aggregate 10 mm (later on site 12 mm)
- Temperature of fresh concrete < 35 °C

A comprehensive Trial Mix Report was submitted by the Contractor. The main findings are summarized below.

Four different mixes were tested under laboratory and site conditions:

Mix No.	W/C ratio	Quantities for 1 m^3 of Plastic Concrete				
		Water (Litres)	Cement (kg)	Bentonite (kg)	Sand (kg)	Coarse aggregate (kg)
M1	2.8	380	136	35	821	671
M2	3.0	380	127	35	700	675
M3	3.2	380	119	35	720	678
M4	3.4	380	112	35	790	681

All mixes were showing a stable slump with little variation during the first two hours. In principle, all 4 mixes meet the target values, but Mixture M1 was finally selected because its permeability and compressive strength is on the safe side and has a favourable secant modulus of < 500 MPa and a strain at failure of > 1.9 %. Details of test results for M1 (pure lab conditions) and M1.1 (site conditions) are as follows:

	Unconfined Compression Test							Triaxial Test			
	7days		14 days		28 days			28 days			
	q_u MPa	E_s MPa	q_u MPa	E_s MPa	q_u MPa	E_s MPa	D gm/cm^3	q_u MPa	ε_f %	E_s MPa	k x 10^{-8} m/sec
M 1	0.55	127	0.76	112	1.03	337	2.025	0.97	2.72	134	0.91
	0.60	49	0.82	88	0.97	272	2.031	0.96	1.93	103	0.89
	0.43	40	0.72	62	1.02	444	2.002	0.94	3.23	90	2.34
M 1.1			0.82	68	0.85	223	2.017	0.97	2.23	95	1.29
			0.74	56	1.00	(66)	2.013	1.03	1.95	132	1.28
			0.83	162	1.25	235	2.036	0.99	1.28	252	0.87

The permeability test results were not as good as expected. Long hours of road transport to an external laboratory was found unfavourable for the Plastic Concrete samples. Thus, special care was observed for the sample transport. As demonstrated during construction, handling with more care, short distance and testing on site eliminated this problem. Based also on the experience with the plastic concrete Mixture M1 used for the Sealing Element construction, the Consultant decided to use Mixture M1 for the Permanent Cut-Off Wall, too.

For the Permanent Cut-Off Wall plastic concrete, the "Alkali Silica Reaction" was also discussed. As the ASR method cannot be applied on the comparably 'soft' plastic concrete, two independent experts from France and Germany were asked: Andre Le Roux from CEBTP France and Dr. Siebel from the Department of Concrete Technology at the FIZ, Düsseldorf, Germany).

Based on the recommendation of the experts, NHBDC concluded that the use of the selected Plastic Concrete Mixture M1 was acceptable for the Permanent Cut-Off Wall, provided that by routine testing it was regularly verified, ensuring that the total alkali-equivalent content of the mix does not exceed 2.7 kg/m^3. This is 10 % less than the 3kg/m^3, which both experts, Le Roux and Dr. Siebel, consider as the potentially deleterious limit of alkali in the concrete mix. This limit was introduced to the ITPs.

4.3 Panel Design

The primary panels were executed with 3 bites and 7.0 m length. Secondary panels were done in one bite with 2.8 m length. The overlapping of primary and secondary panels was 0.5 m according to PTS.

The Contractor proposed to execute the wall from only one working platform at level 48.8 m asl in order to save time for construction. The increased excavation and slurry volume was at his own account. The "free" excavated upper trench was filled with natural sand.

4.4 Change of Keying in the Silt/Clay Layer

Based on intensive laboratory tests, the properties of the Silt/Clay layer were determined and assessed in such a way that the keying of the Cut-Off Wall in this layer could be reduced from 3.0 to 1.5 m. The decision was supported by the experience of the quite exact determination of the actual penetration depth during construction of the temporary 'Sealing Element Cut-Off Wall'. In addition, the factor of safety against uplift of the remaining part of the Silt/Clay layer at the bottom of the trench during excavation could be increased considerably. The head of the artesian pressure below the Silt/Clay layer was defined as 64.5 m asl and during construction maximum values of approximately 64.4 m asl were measured in summer 2004.

4.5 Change of Capping

Based on intensive deformation calculations and experience with mixture M1 properties for the 'Sealing Element' such as the Modulus of Elasticity and the Strain at Failure, the elastic layer on top of the wall head was omitted. The structural safety of a rigid connection between the plastic concrete Cut-Off Wall and R.C. structures was verified.

4.6 Trench Stability

The trench stability calculations were submitted by the Contractor. The results are as follows for three different groundwater tables within the Construction Pit:

Groundwater level 46.00, Factor of Safety = 1.55
Groundwater level 42.00, Factor of Safety = 1.68
Groundwater level 40.00, Factor of Safety = 1.68

5 EQUIPMENT, WORKING SEQUENCES, STAFF

5.1 Equipment and Site Installation

The same trench cutter which was used for the execution of the Sealing Element works, BAUER BC 30, was used as excavation tool mounted on a LIEBHERR 883 crane. It consists of a heavy steel frame with two gear boxes attached to its bottom end, which rotate in opposite direction around horizontal axis. Cutter wheels are mounted into the gear boxes. As they rotate, the soil underneath the cutter is continuously removed, mixed with the bentonite slurry in the trench and sucked towards the openings of the suction box.

The bentonite slurry, charged with the loosened soil, is pumped by a centrifugal pump, located right above the cutter wheels through the slurry pipe within the cutter frame, via the mast head in the slurry pipe system to the de-sanding plant, BAUER BE 500, where it is de-sanded and returns back into the trench.

The verticality of the trench cutter and thus the trench alignment was measured by two independent inclinometers in y- and x-axis. Also the wheel pressure which is very helpful in the determination of a change of soil conditions could be watched on a computer screen.

Details for the equipment are attached to the Method Statement, **Attachment 2.** The Site Installation area was located in the Construction Pit (Phase 1), upstream of the wall alignment and on the left embankment between Powerhouse and backfilled Diversion Canal for Phase 2.

5.2 Working Sequences

The construction of the Permanent Cut-Off Wall (Phase 1 & 2) strictly followed the approved Method Statement, Revision D, which is attached as **Attachment 2.**

Guide Walls:
Reinforced precast concrete guide wall elements of 1.5 m height and 6 m length were constructed and installed by the use of a Mobile Crane to ensure the correct alignment of the Cut-Off Wall trenching. This also gives support to the upper trench stability, which is affected by the heavy weight of the cutter equipment.

Excavation:
It has to be differentiated between Primary (P) and Secondary (S) panels:

Primary panels had a length of 7.0 m. The secondary panels had a length of 2.8 m (0.5 m overlapping to primary panels). The primary panels were executed with 3 bites (left bite 2.8 m, right bite 2.8 m and remaining middle bite of 1.4 m). The bentonite slurry in the open trench guarantees its stability and was exchanged at the final depth after having been charged with sand and silt during excavation.

Secondary panels were located between primary panels, and 1.8 m distance were kept in between to allow the secondary panels an overcutting of 0.5 m in each of the two neighbouring primary panels when executing after 7-14 days hardening of the plastic concrete. This procedure promised a good contact between the panels and should form an impermeable vertical joint. (The temporary Sealing Element Cut-Off Wall which was deeper was carried out with overlapping of panels of 0.2 m only and verified best results).

The tolerance for the verticality of the trench was specified in PTS to a minimum of 0.3 % of the excavation depth, the final trench depth was defined by a minimal keying into the Silt/Clay layer of 1.5 m. The depth tolerance was set to – 0 / + 0.5 m in order to limit the maximum depth for the stability reasons of the remaining Silt/Clay layer below the bottom of the trench against uplift forces.

Concrete Pouring:
Plastic concrete was supplied by concrete mixer trucks, and pouring was done by tremie pipe. For panels of 2.8 m length one tremie pipe is sufficient, for larger ones two tremie pipes were used. The tremie was placed 0.5 m above the trench toe level when concreting starts. During concreting, the tremie pipes were kept at least 3 m continuously immersed in the fresh concrete. This had to be kept while concreting when sections of the tremie pipe string was taken out during the rising of concrete in the trench.

5.3 Staff

The Contractor subcontracted the Permanent Cut-Off Wall construction works to BAUER Egypt, which was executing the works with the following staff numbers:

1 Site Manager
7 Engineers (Site, Quality, Surveyor, Mechanical, Electrical)
5 Foremen
8 Operators
48 skilled and unskilled labourers (including office and safety personnel)

The Main Contractor Lot 1, Civil Works, was supervising the performance of his Subcontractor with one engineer on a permanent basis and several engineers partly including the Quality Control.

The Consultant's staff included the Resident Engineer Geotechnics (Expatriate) for the approval of method statements, Inspection and Test Plans, and geotechnical calculations in connection with NHBDC's Home Office support. The construction supervision team was formed by the Resident Engineer and one to two engineers.

6 TRIAL TEST BOX PUMPING TEST

Before starting the temporary Sealing Element works, the Contractor carried out a Trial Panel Box on the Left Bank to evaluate the efficiency of the Sealing Element Cut-Off Wall construction method regarding construction tolerances and water tightness of over-cut joints and to assess the expected permeability of the constructed wall. The Consultant/Employer accepted the trial test result also for the Permanent Cut-Off Wall, especially because the same Mixture M1 was chosen for both walls. For completeness, the results shall be documented here, too:

The outer dimensions of this box were as follows:

Vertical:	56.0 m
Horizontal:	9.8 x 8.4 m
Level top of box:	65.00 m asl
3.0 m keying into Silt/Clay layer at	9.00 m asl
Level top of Silt/Clay layer:	12.00 m asl

In the Trial Panel Box, a well was drilled to elevation 30.00 m asl and seven piezometers were installed for measuring the effect of the Pump Test on the vicinity inside and outside the box. The Pump Test was conducted with a pump of a capacity of 3 to 5 litres per second at a head of approximately 20 m. Pumping was conducted until the water level remained constant in the inner piezometer for 5.5 hours. The waterflow was continuously measured and the piezometer readings were carried out also for the recovery over a period of almost one month. The data and results are as follows:

- Average measured water discharge was 0.30 m^3 per hour at steady state.
- Water level outside the trial box was unchanged and stayed at level 60.83 m asl and no difference in water level was noticed between the piezometers.
- The water level inside the box was lowered to level 39.81 m asl, a difference Δ H of 21.02 m.
- Internal dimensions of the trial box are 7.6 x 5.4 m, hence the inner perimeter length is: 2 x (7.6 +5.4) =26.0 m.
- Water pressure acting into the wall at level 39.81 m asl is: P=21.02 m x 10 kN/m^3 = 210.2 kN/m^2.
- Nominal wall thickness = 0.80 m.
- Under the assumption that the Silt/Clay layer is "impermeable" the wall permeability was determined to k = 3.2 x 10-9 m/s.

It was concluded that the suitability of the used Plastic Concrete with respect to permeability is proven and the PTS target value of 1 x 10^{-8} m/s is verified. The over-cutting of 20 cm to form the joints between the panels proved to be adequate for achieving the required water tightness even at the depths exceeding 56 m.

7 DESCRIPTION OF CONSTRUCTION WORKS

7.1 General Progress

For the Phase 1 of the Cut-Off Wall, the first panel excavation started on 04 September 2004 and the last panel was poured on 09 November 2004. The Contractor followed in principle his proposed construction sequences, **Attachment 6**.

The approximate level of the Silt/Clay layer was known by investigation boreholes. Special care was taken from about two meters above the theoretical top of this layer during the excavation by the trench cutter where the top of the layer was met. The monitoring devices in the trench cutter cabin indicated a change of cutting resistance. Parallel to this, the output of the desander plant was observed closely and the soil profile change was clearly visible. Thus, with these combined methods, an accuracy for the measurement of the top of the Silt/Clay layer can be estimated by – 0.10 m from the actual existing level. From this measured depth, the panel keyed in the Silt/Clay by 1.5 m as specified.

The construction performance is documented in a table, **Attachment 7**. In principle, 1 primary panel and 2 secondary panels were executed per working day.

For the Phase 2 works started on 02. June 2007 on the left embankment and were concluded on this location on 09. August 2007 (146 panels). After transfer of equipment to the right embankment works restarted and were concluded for the 55 m section of wall on 28. August 2007 (25 panels). Due to previous experience on Phase 1, works progressed well on Phase 2 and were completed 1 month ahead of schedule.

7.2 One Working Platform (Phase 1)

According to design, it was foreseen to work from different working platforms, which follow the Construction Pit excavation schedule with idle time on the heavy equipment. The Contractor proposed to execute the works from only one level which basically is from the highest below the concrete structure, which is the level below the Sluiceway. According to the Contract, the minimum working platform levels here was 48.8 m asl. This proposal was approved to facilitate the works and save time. The higher excavation and slurry volumes were on the Contractor's account. The panels were filled to the design level and some safety margin above by plastic concrete. The remaining trench was filled with sandy material out of the Construction Pit.

7.3 Method Statements

In principle, the 'Method Statement' for the Permanent Cut-Off Wall (**Attachment 2**) followed the Method Statement of the 'Sealing Element' with some modifications as follows:

- The over-cutting of the primary panels had to follow the value given in the PTS: 0.5 m.
- The sampling and testing frequency was increased per sqm of the wall following the PTS.
- For this permanent structure, the Alkali Reactivity (ASR) for the plastic concrete was a matter for investigation and approval.

Because the Contractor choose to work from one working platform only, he had to submit Method Statements for the excavation of the Cut-Off Wall in place, divided by the 'Horizontal Capping' **(Attachment 3)** and 'Vertical Step Capping' **(Attachment 4)** between the different levels.

For these steps, the Contractor proposed to demolish the vertical walls above the lower level, to follow the earth excavation slopes to the higher level. This was approved with the possibility to save the wall at least in parts, if possible. During the excavation, the Contractor cut the vertical wall to the designed shape at the Sluiceway Abutment Pier and demolished the part at the Powerhouse Intermediate Pier.

A further separate Method Statement was submitted for the construction of the Cut-Off Wall section located in between the rail beams of the Main Gantry Crane (**Attachment 5**).

7.4 Construction Works

The construction works data are summarized in a table of **Attachment 7.** In general, 1 primary and 2 secondary panels were completed per working day. The over-consumption of plastic concrete against the theoretical volume was in the range of 4 % to 19 % with an average of approximately 12 % with a tendency of lower consumption of the secondary compared to the primary panels.

The difference between the theoretical panel depth and actual depth was – 6.24 m for the sum of all panel lengths, which is a deviation of only – 0.25 % of the theoretical depths of all panels or appr. -7 cm per panel.

The top of the Silt/Clay layer was found between 35.5 m (at Panel No. P01 and S1) at the western end and 26.5 m (P34) towards the eastern end. These means that the top of the Silt/Clay layer was found between the levels 13.3 and 22.3 m asl.

7.5 Deviation of Panels from Verticality

The inclinometer measurements in x- and y- direction show practically a 'Zero' deviation. In some cases, the deviations undulated around the vertical line by less that 3 mm. There was one case at Panel S38, where the deviation was measured 5 mm at 2 m above final depth. Even in this case, the measured deviation 2 m deeper at end depth was 1 mm only and is negligible.

There are no significant differences between primary and secondary panels concerning the negligible deviations. This result demonstrates also, that there were no obstacles in the ground which could affect the verticality.

7.6 Special Occurrences

In the Sluiceway, the head of the Cut-Off Wall level is 46.8 m asl, which is 2.0 m below the working platform at level 48.8 m asl. In this area, deficiencies of the Cut-Of Wall were observed at the connection joint of panels. The plastic concrete was replaced by a mixture of bentonite and sand. These parts were fully removed and cleaned, leaving some voids of different size up to maximum 0.8 m below the Cut-Off Wall head with comparably small extent. These gaps were filled with structural concrete during casting of the capping structure. No deficiency reached below the capping bottom level.

The excavated open vertical part of the Cut-Off Wall at the Sluiceway Abutment Pier was hit by the beam of a mobile crane when it lost balance during placing of precast L-walls around this area. Because of this accident, a part of the wall head was cut off. The whole wall area was jointly inspected and no additional damage could be observed. The cut-off part will be filled by structural concrete of the capping in this area.

8 QUALITY ASSURANCE, FIELD AND LABORATORY TESTS

8.1 General

To ensure the constant quality of construction works, 5 different Inspection and Test Plans (ITPs) with the following inspections and tests were worked out and followed.

ITP - Construction of the Permanent Cut-Off Wall

- Submit Manufacturer's Certificate for Bentonite including its compliance with Standard and Specifications.
- Sampling and testing the fresh bentonite slurry at the bentonite mixing plant.
- Sampling and testing the recycled (working) bentonite slurry at the bentonite mixing plant.
- Inspection (visual inspection and joint survey) after placing the precast elements (Guide Wall Inspection).
- Inspection (visual inspection and joint survey) after backfilling and prior to starting the excavation of the panel.
- Inspection during the excavation process above the silt/clay layer.
- Inspection during the excavation process in the silt/clay layer.
- Sampling and testing the bentonite slurry from the trench before concrete placement (samples pumped out through the return line of the cutter after bentonite exchange).
- Sampling and testing of plastic concrete.
- Inspection prior to starting the concrete placement.
- Inspection during concrete placement.
- Inspection on completion.
- Inspection after panel casting (safety procedure).

ITP – Testing of Cement for Permanent Cut-Off Wall

- Submit Manufacturer's Certificate for the Cement and Quality History Records of the factory indicating its compliance with the Standards and Specifications.
- For the material approval, the following tests shall be performed for suitability:

  – Sampling and testing (physical and chemical) of Cement to determine the following characteristics:

    Flexural strength at 2 and 28 days
    Compressive strength at 2 and 28 days
    Initial and final setting time on pure paste
    Le Chatelier stability
    Chemical Analysis
    Alkali Equivalent ($Na_2O + 0.658\ K_2O$)
    Blaine's Specific Surface

  – Obtain from the Manufacturer's a Quality History for a period of one year preceding testing for proportioning of the trial mixes.

- Provide the Manufacturer's Certificate reports and the continuation of the Quality History Record in accordance with DIN EN 197 upon the delivery of each batch of Cement.
- Receiving inspection of the Cement when it is delivered in bags.
- Inspection of stored Cement.
- Sampling and testing of the Cement during the performance of the work as the following:

  – Le Chatelier Stability
  – Flexural and compression strength at 2 and 28 days
  – Initial and final setting time on Pure Paste
  – Blaine's specific surface
  – Chemical Analysis
  – Alkali Equivalent ($Na_2O + 0.658\ K_2O$)

ITP – Testing of Aggregates for 'Permanent Cut-Of Wall'

- For proportioning and testing of Concrete trial mixes, the following tests shall be performed (Initial Selection):

  – Sand (0-4)

  Apparent Specific Gravity
  Water Absorption
  Chloride Content (water soluble)
  Sulfate Content (acid soluble)
  Alkali Equivalent
  Gradation
  Organic Impurities
  Soundness (magnesium sulfate)

  – Gravel (4-12)

  Apparent Specific Gravity
  Water Absorption
  Chloride Content (water soluble)
  Sulfate Content (acid soluble)
  Gradation
  Soundness (magnesium sulfate)
  Alkali Equivalent

- Sampling and testing of Aggregate during the performance of the work as the following (Routine Testing):

  – Sand (0-4)

  Apparent specific gravity
  Water Absorption
  Chloride Content (water soluble)
  Sulfate Content (acid soluble)
  Alkali Equivalent
  Gradation
  Organic impurities
  Soundness (magnesium sulphate)

  – Gravel (4-12)

  Apparent specific gravity
  Water Absorption
  Chloride Content (water soluble)
  Sulfate Content (acid soluble)
  Gradation
  Soundness (magnesium sulphate)
  Alkali Equivalent

ITP - Bentonite Testing in the Batching Plant

- Submit Manufacturer's Certificate for Bentonite indicating its compliance with Standards and Specifications.
- Calibration of the mixer marks indicating volume of water used for mixing.
- Sampling and testing the mixed Bentonite Slurry from storage silos.
- Chemical Analysis

- Alkali Equivalent

ITP - Plastic Concrete Production for Permanent Cut-Off Wall

- Inspection and testing of Cement.
- Inspection and testing of Aggregate.
- Inspection and testing of Bentonite mix at batch plant.
- Submit Plastic Concrete Design Mix.
- Trial Panel Test.
- Sampling and testing of the fresh Plastic Concrete (Slump Test and Temperature).
- Sampling and testing of Plastic Concrete during the performance of the work as the following:

  – Uniaxial Compressive Strength, one set of 3 samples for 14 days, one set of 3 samples for 28 days and one set of 3 samples for testing on 56 or 90 days.
  – Uniaxial Modulus of Elasticity
  – Triaxial Permeability Test
  – Triaxial Shear Test
  – Triaxial Modulus of Elasticity
  – Erodability Test
  – Alkali Equivalent (calculation from testing Cement, Sand, Coarse Aggregate and Bentonite)

For Quality Assurance, a daily report for each panel construction works was submitted to the Employer and to the Consultant. For Panel No. P08 the signed reports with Inspection Check List is attached as an example in **Attachment 8.**

8.2 Fresh Plastic Concrete

Fresh plastic concrete was checked upon delivery for each truck before pouring. Slump limits were set between 220 and 250 mm according to previously performed trial mixes and with the experience from the Sealing Element Construction Works. Daily experience shows average slumps around 230 to 245 mm. The maximal fresh concrete temperature was accepted up to 35 °C because of the groundwater temperature of some 23 °C.

8.3 Hardened Plastic Concrete

During production of the plastic concrete, samples of fresh concrete were taken and tested after 14 and 28 days, and for some percentages after 90 days. The evaluation of the site lab test results was carried out for the total Phase 1 Cut-Off Wall, which is documented in **Attachment 9**. Furthermore, triaxial tests were carried out in an external laboratory and are also documented in **Attachment 9.** The sequence and results for the total available test numbers are summarized as follows:

Unconfined Compressive Strength (UCS) Testing

As carried out with the trial mixes, unconfined compression tests were performed on a daily basis during construction in the site laboratory. The specimens had a nominal diameter and also height of around 75.0 mm, thus a height to diameter ratio of 1.0. For each specimen, the top and bottom surfaces, in order to become perfectly horizontal, were capped with sulphur.

Conventional strain-controlled unconfined compression tests were carried out according to ASTM D 2166-98a with a strain rate of 0.21% /min (0.16 mm/min). For each test, the stress-strain curve was plotted. Values of unconfined compressive strength (q_u), strain at failure (s_f) as well as secant modulus defined at 30% to 70 % of the unconfined compressive strength ($E_{s(30\%-70\%)}$) and the unit weight were determined.

The evaluation of the UCS test results for 28 and 90 days are as follows:

	Uniaxial Test 28 days				Uniaxial Test 90 days			
	Unit weight (gm/cm^3)	UCS (MPa)	Es (MPa)	Strain at Failure %	Unit weight (gm/cm^3)	UCS (MPa)	Es (MPa)	Strain at Failure (%)
Test Nos.	231	231	76	77	75	75	25	25
Average	2.04	1.25	236.7	1.65	2.05	1.41	199.5	1.56
Stand. Dev.	0.04	0.19	219.7	0.52	0.04	0.19	127.9	0.29
Maximum	2.16	1.69	1395.9	2.93	2.16	1.87	631.4	2.17
Minimum	1.90	0.71	53.3	0.80	1.97	0.90	68.6	0.91

	Uniaxial Test 14 days				Triaxial Test 28 days		
					Shear		Es (MPa)
	Unit weight (gm/cm^3)	UCS (MPa)	Es (MPa)	Strain at Failure %	ϕ (^{0})	c_u (MPa)	
Test Nos.	75	73	25	25	18	18	18
Average	1.96	1.03	146.1	1.62	38.1	0.17	86.4
Stand. Dev.	0.19	0.16	95.0	0.43	3.6	0.06	19.0
Maximum	2.09	1.48	443.5	2.51	44.0	0.28	128.9
Minimum	0.83	0.78	36.1	0.88	31.0	0.10	61.9

Permeability Testing

The permeability was tested in triaxial cells in an external laboratory. According to the PTS, the specified target value for the permeability is $k \leq 1 \times 10^{-8}$ m/s. The evaluation of the tests is as follows and shows the average of all test results with lower permeability than specified:

Tested on day		28 days
Test Numbers		18
Permeability k (m/s)	Min	1.0×10^{-9}
	Max	1.8×10^{-9}
	Average	1.3×10^{-9}

Erodability Testing

For the 'Permanent Cut-Off Wall', erodability tests were carried out as pinhole tests in the site laboratory. Plastic Concrete cylinders of 320 mm height were provided with a pinhole of 12 mm diameter and the test was carried out with water under pressure of 4 Bar. After flow steps of approximately 150 to 170 l, the fines were measured remaining on ASTM Sieve No. 200 and the curve of material on the sieve plotted. Normally, the material left on the sieve decreased with the number of steps indicating safety against erosion. Furthermore, experience with triaxial erosion tests carried out on the same plastic concrete Mixture M1 for the "Sealing Element Wall" demonstrated safety against erosion up to the tested maximum hydraulic gradient of i = 130. For each tested sample, a curve "permeability coefficient" versus hydraulic gradient was plotted. These curves evidenced that the permeability did not increase when the hydraulic gradient was raised. Thus, the triaxial tested samples were found not sensitive to erodability. For details, it is referred to NHBDC's Sealing Element Construction Report, September 2004.

The results showed that the plastic concrete with an UCS in the range of 0.8 ÷ 1.4 MPa is safe against erodability. This is in line with published research Duellmann / Heitfeld "Erosionsbestaendigkeit von Dichtwaenden unterschiedlicher Zusammensetzung" (Erosion resistance of slurry Cut-Off Walls of different composition) which shows that plastic concrete with UCS of 0.3 to 0.4 MPa is considered to be resistant to erosion up to a hydraulic gradient of i = 90 for sandy soils and i = 70 for gravely soils. With a maximum gradient in the Cut-Off Wall $i = \Delta h/d = 8.6/0.8 = 10.75$ and an anticipated UCS of > 0.7 MPa the plastic concrete of the Cut-Off Wall can be considered safe against erosion.

The Plastic Concrete test results during construction are documented in laboratory summary sheets for the permanent Cut-Off Wall in **Attachment 9.**

9 CONSTRUCTION WASTE DISPOSAL

Disposal of Waste from Desander

The bentonite was almost entirely recovered from the trench cutter excavation slurry by the de-sander. The sand and gravel parts of the excavated soils were separated in the process. The sand with slight remains of bentonite was dumped into the Flood Channel as "Unclassified Earth Fill" and the gravel was used for stabilization of construction roads or similar.

Disposal of Used Bentonite Slurry

The slurry was poured into ponds near to the bottom of the Flood Channel. After some drying out, the bentonite ponds were covered by unclassified sandy fill. In order to facilitate the drainage condition for later irrigation, ditches were excavated through the bentonite layer in a grid of 30 m and refilled, mixed with sand.

10 SUMMARY

The works for the Cut-Off Wall followed closely the design based on revised and approved deformation calculations, applying the finite element method and using an approved design mixture after trial mix tests for the plastic concrete carried out for the Sealing Element Cut-Off Wall assessed suitable. Exploratory boreholes were carried out to prove the existence, property and top level of the Silt/Clay layer as a bottom seal of the Construction Pit. All items and parameters were continuously controlled during construction without any gaps.

The construction for the Phase 1 wall was carried out from one working platform level at 48.8 m asl only. In the natural ground with prevailing pleistocene sands and gravely sands, the excavation by trench cutter on primary (3 bites) and secondary panels (1 bite) showed no significant disturbances or losses of slurry.

The general progress was 1 primary panel and 2 secondary panels per working day. Only one short machine breakdown was observed, which was repaired and the panel excavation and pouring could be completed on the same day.

The construction for the Phase 2 wall was carried out from platform levels 67.1 and 68.1 m asl. Apart from natural ground the Cut-Off wall crossed the backfilled Diversion Canal in silty sands. Bed and slope protection material of the Diversion Canal had been carefully removed in the alignment of the Cut-Off wall before backfilling the canal with silty sand.

The general progress during Phase 2 was 1 panel per day for panels reaching the impermeable layer below the Pleistocene sands. For short panels across the backfilled diversion canal 2 panels could be poured per day.

Execution of the Cut-Off Wall needs special precautions at the vertical connection parts of the wall to the concrete structure. At the Intermediate Pier, the highest step, the Contractor chose to demolish the wall following the excavated slope and rebuild it later stepwise during backfilling. At the Sluiceway Abutment Pier, the Contractor chose to shape the vertical part to the designed dimensions.

For the connection of the Phase 2 wall to the Powerhouse and the Navigation Lock a vertical recess had been created in the concrete structure.

The verticality of the panels in x/y direction was controlled continuously by inclinometer devices in the cutter frame. Deviations from the verticality could be handled by the operator to be less than 5 mm, mostly less than 3 mm, at the final depth of the panel excavation, which can be considered, practically as 'Zero' deviation. The plastic concrete over-consumption occurred quite continuously during the filling of each open panel trench. Significant sharp steps in the over-consumption cumulative curve were not observed. The over-consumption varied between 4 and 19 % with an average of approximately 12 %.

The quality control by laboratory tests with the plastic concrete verified a comparably narrow range of results for such a material, with average results more favourable than the target values such as higher Unconfined Compression Strength, lower E-Modulus, less permeability and verified the sufficient safety against erosion.

The sandy part of the construction waste from the de-sander was dumped into the Flood Channel as Unclassified Earth Fill. Separated gravel was used for stabilization of construction roads or similar. The used bentonite slurry was dried out in ponds near to the bottom of the Flood Channel. After drying out, the bentonite layer was covered by sandy material. Later on a grid of trenches was excavated through the bentonite and refilled by surrounding sandy material to improve the permeability for drainage and for irrigation to come.